Pollution in Areas near the Pompano Beach Sewage Outfall

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This paper reports the results of studies designed to determine whether a sewerage outfall contributes to the pollution of adjacent beaches. The methods employed were limited to a study of the currents and to examination of the water for coliforms in the areas of the sewerage outfall, the Hillsboro Inlet and adjacent beaches located in the city of Pompano Beach, Florida.

Pearson (1965) reviewed the literature to 1955 and developed mathematical formulae for the prediction of the rate of dilution and diffusion of sewage in the area of a marine outfall. More recent investigations reported by Garber (1960), the Alan Hancock Foundation (1965) and Saville (1966) have employed chemical analyses, dye-plume studies and coliform counts to determine the fate of organic wastes discharged into a marine environment.

The physical features of the area studied are shown in Nautical Chart 845 SC which is reproduced in part in Fig. 1. The outfall line extends east approximately 2500 yards from the shore line and approximately 3400 yards southeast of the Hillsboro Inlet. The proximity of the Hillsboro Inlet complicates the interpretation of data since polluted water from the Intracoastal Canal usually flows south along the beach during an outgoing tide. This mixing of waters from two sources of pollution requires an extrapolation of data to determine the probable extent of pollution from the outfall.

The outfall pipe has an inside diameter of 30 inches and the terminal outlet is inclined approximately 22° from the ocean floor. The vertical distance from the outlet to the surface of the water is approximately 87 feet.

Sewage and sludge receive a primary treatment of comminution, removal of floatables, and chlorination to reduce odor. The current volume of sewage is approximately 2.2 million gallons per day with the highest flow rates occurring between 0900-1100. Sewage sludge which settles to the bottom of the holding tanks is dumped through the outfall daily between the hours 0900-1200. The mean flow rate during the peak pumping time is estimated at 3000 gallons per minute.

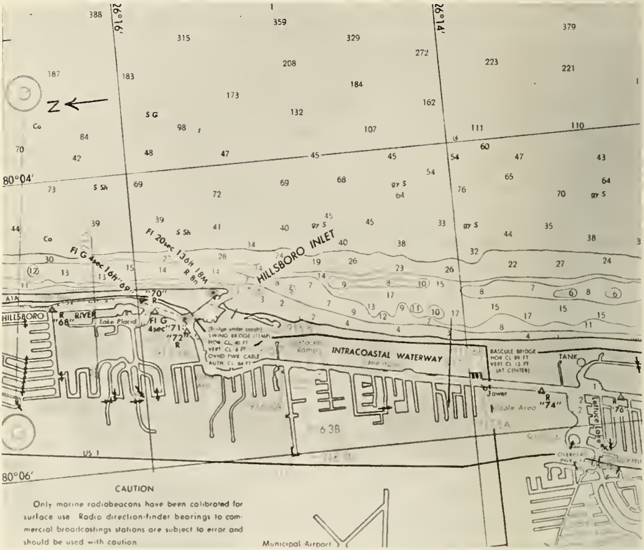

Fig. 1. Section of Nautical Chart 8575C (1965) showing location of Pompano Beach Outfall.

Procedures and Methods

All samples used in this investigation were collected during the morning hours from 0900-1100 for the period extending between December 1966 and September 1967. Surface samples were collected in sterile wide mouth bottles with screw caps. Deep samples were taken with a Bacteriological Water Sampler (CM[2], Inc., Mt. View, California). Collection of samples and subsequent examination followed procedures as recommended in Standard Methods (American Public Health Association, 1962). All samples were held in ice until used in the laboratory. No samples were held longer than four hours. The membrane filter (Millipore) was employed with m Endo Broth MF for measurement of the coliform group. A small number of samples were examined for fecal coliforms using the procedures and FC Medium described by Geldreich

TABLE 1
Summary of oceanographic conditions and appearance of boil near outfall

Number and Date	Surface Boil	Sea Condition	Wind (from) Direction	Wind (from) Speed	Current (toward) Speed	Current (toward) Depth	Current (toward) Direction
12/22/66	+	calm	NNW	4	0.4	50	SSE
12/29/66	+	calm	SE	6	0	50	
1/26/67	+	3–4 ft	SE	10	0.3	50	ENE
2/ 2/67	+	1–3 ft	ESE	8	0.3	50	N
2/19/67	+	calm	SSE	1	0.5	10	N
					0.3	20	N
					0.1	50	N
2/21/67	+	1–3 ft	S	2	—	12	SSE
3/ 9/67	+	1–3 ft	SE	8	0.3	12	WSW
3/16/67	+	4–5 ft	NW	18	0.6	12	N
4/ 6/67	+	1–2 ft	SE	5	0.6	12	N
4/20/67	+	2–3 ft	NE	10	0.3	12	SSW
4/25/67	+	calm	NE	3	0.6	12	S
5/10/67	+	calm	calm	0	1.5	12	N
5/24/67	—	calm	SW	3	1.0	12	N
5/26/67	+	calm	SW	3	0.6	12	SW
5/31/67	+	calm	SW	6	0.2	12	SSW
6/ 2/67	—	2–3ft	NE	10	1.3	12	SSW
6/ 7/67	—	0–1 ft	SE	5	0.4	12	NE
6/ 9/67	—	calm	S	2	0.9	12	SW
					0	60	SW
6/16/67	—	1–3 ft	SSW	4	0.5	12	NE
6/22/67	—	calm	NNE	2	0.9	12	NE
6/27/67	—	3–4 ft	S	12	1.0	12	NE
					0.7	60	N
					0.6	80	N
6/29/67	—	1–2 ft	SSW	4	1.2	12	N
7/18/67	+	4–6 ft	SSE	18	0.6	12	NNW (0900 EDT)
7/18/67	+	2–4 ft	ESE	12	0.3	12	WSW (1100 EDT)
7/20/67	—	4–5 ft	ENE	15	1.2	12	NNW
7/25/67	+	4–5 ft	SE	15	0.5	12	NNW
7/27/67	—	2–3 ft	SSE	8	2.0	12	SW
8/ 1/67	—	calm	NNE	3	1.2	12	N
8/ 3/67	—	3–4 ft	SSE	10	1.1	12	NE
8/ 9/67	—	1–2 ft	SE	4	0.7	12	SW
8/12/67	—	3–5 ft	S	15	1.8	12	N
8/14/67	+	calm	N	2	0.8	12	N
8/16/67	+	2–3 ft	NE	8	0.7	12	N
8/21/67	+	3–4 ft	SE	15	0.5	12	S
8/23/67	—	2–5 ft	E	10–18	0.8	12	N

\+ = boil visible
— = boil not visible

et al. (1965). Unless otherwise indicated, all counts are given as coliforms.

Direction and velocity of currents were determined with current crosses usually set at a depth of twelve feet. Positions were determined by taking cross-bearings with an Ilon Position Finder. Calculated precision of the positions is ±25 yards in relatively calm seas to ±50 yards in rough seas.

Observations and Results

Currents at the Outfall Site. Table 1 summarizes the observed oceanographic conditions in the area of the outfall during the times samples were collected. The presence or absence of a boil at the surface generally can be correlated to the velocity of the current. With two exceptions, the boil was always present with current velocities below 0.7 knots and always absent with current velocities above 0.8 knots. No correlation with the direction of the current was noted.

During an ebbing tide, water from the Hillsboro Inlet usually

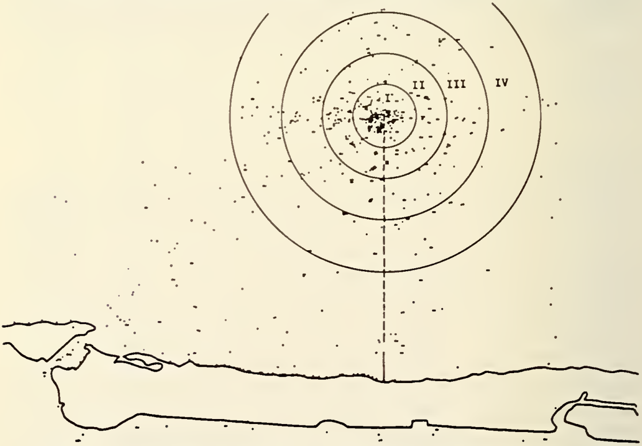

Fig. 2. Approximate location of each sample collected: Zone 1, 0-300 yards; Zone 2, 300-600 yards; Zone 3, 600-1000 yards; Zone 4, 1000-1500 yards from the outfall.

moved south as a littoral current, and less frequently moved southeasterly toward the outfall. On one occasion at low slack tide, brown, turbid water from the Intracoastal Canal had moved southeast to a point only 600 yards from the outfall.

Bacteriologic Analysis at the Outfall. During the early phases of this study, samples were collected near the surface and at varying depths. At locations near the boil, surface samples usually gave a higher coliform count than samples collected at depths of 20 and 50 feet. In areas distant from the boil no significant differences in counts could be related to varying depths. Subsequently, most samples were collected at approximately one foot below the surface of the water.

Figure 2 shows the approximate points of collection for most of the samples tested. These points of collection do not show a random distribution since the primary objective was to determine the maximum pollution near the outfall and the dilution rate in terms of the distance required for the reduction of this pollution. The areas around the outfall have been separated into four zones for convenience of reference and analysis of data. These zones were established after all samples were taken. Although zones of equal area or a larger number of zones would provide more points for graphic analysis, this arrangement does not provide an adequate number of samples for evaluation in each area.

TABLE 2

Summary of coliform counts per 100 ml in zones around the outfall

Areas	Boil	Zone 1* 0–300 yds	Zone 2 300–600 yds	Zone 3 600–1000 yds	Zone 4 1000–1500 yds
Maximum	390,000	390,000	202,000	9,300	584*
Mean	81,000	19,430	6,292	337	48**
Median	61,000	300	37	16	19
Minimum	3,000	0	0	0	0
Number of Samples	21	126	92	73	52
% Samples above $10^3/10^2$ ml	100	42	21	5	2

*Zone 1 inclues samples in boil
**Values obtained by excluding a single high count of 7,400

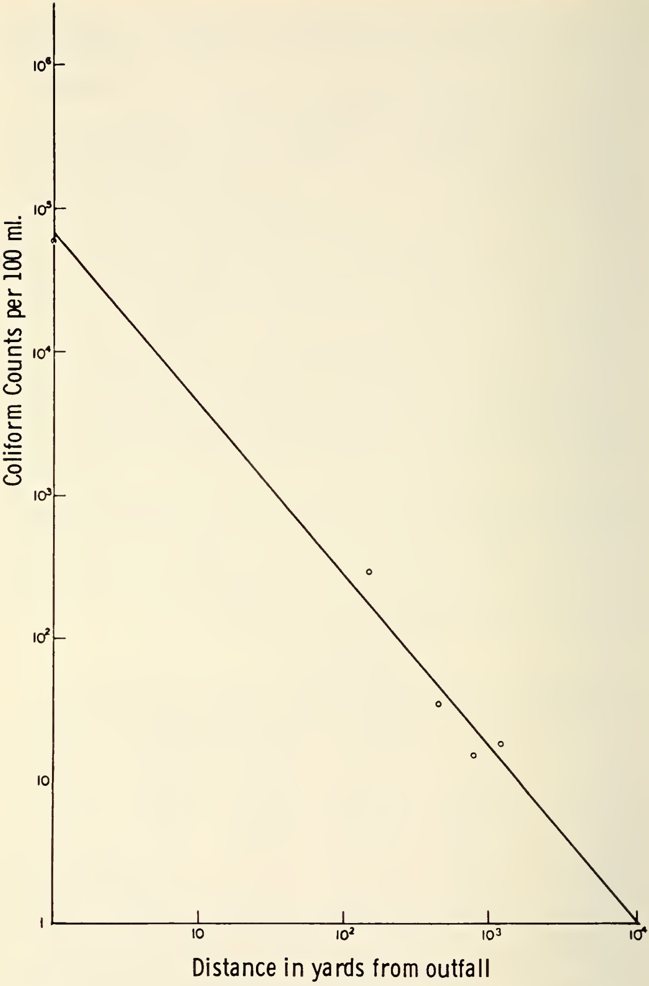

Fig. 3. Mean coliform counts plotted against mean zone distance from the outfall (semi-log transformation).

A summary of the coliform counts of the samples in each area is given in Table 2. Samples from intracoastal waters encroaching from the Hillsboro Inlet, as determined by turbidity and color, are excluded from these data. The wide differences between mean values and median values in all zones are characteristic of pollution by particulate material and indicate the non-uniform distribution and slow mixing of the sewage with the surrounding water. These differences decrease with distance from the outfall.

When logarithms of the mean values are plotted against the arithmetic median distance of each zone, the points approximate a straight-line curve as shown in Fig. 3. The slope of this curve represents an approximate logarithmic reduction in counts with increasing distance from the outfall. Since the decrease in coliform counts with distance from the source of pollution is effected by both dilution and rate of death, the term *decimal reduction distance* is used here to denote the distance required to reduce the coliform count by a factor of 10 (90 per cent). On the curve for the mean values, the decimal reduction distance is approximately 400 yards. A semi-log transformation of the percentage of samples showing counts above 1000 per 100 ml also gives a straight-line correlation.

The median values listed in Table 2 are not amenable to semi-logarithmic correlation as is the case with the mean counts. The points for median counts approximate a straight line when both variables are plotted as logarithms as shown in Fig. 4.

An analysis of the data summarized in Table 2 by the method of multiple regression shows a high degree of inverse correlation between coliform counts and distance from the boil ($R^2 = 0.98$).

The two sets of data lead to different conclusions. Extrapolation of the mean values show mean coliform counts approaching zero at approximately 1800 yards from the outfall, while a similar extrapolation of median values indicate that median coliform counts of 7 per 100 ml would be found at the beach, 2500 yards from the outfall. Analyses of frequency distribution of the coliform counts show that maximum frequency is weighted sharply toward lower values. This type of distribution gives greater validity to median values. Interpretations of single-source diffusion data obtained by other workers (Alan Hancock Foundation, 1965; Brooks, 1960) suggest that the data of median correlations would be the more reliable of the two sets of data.

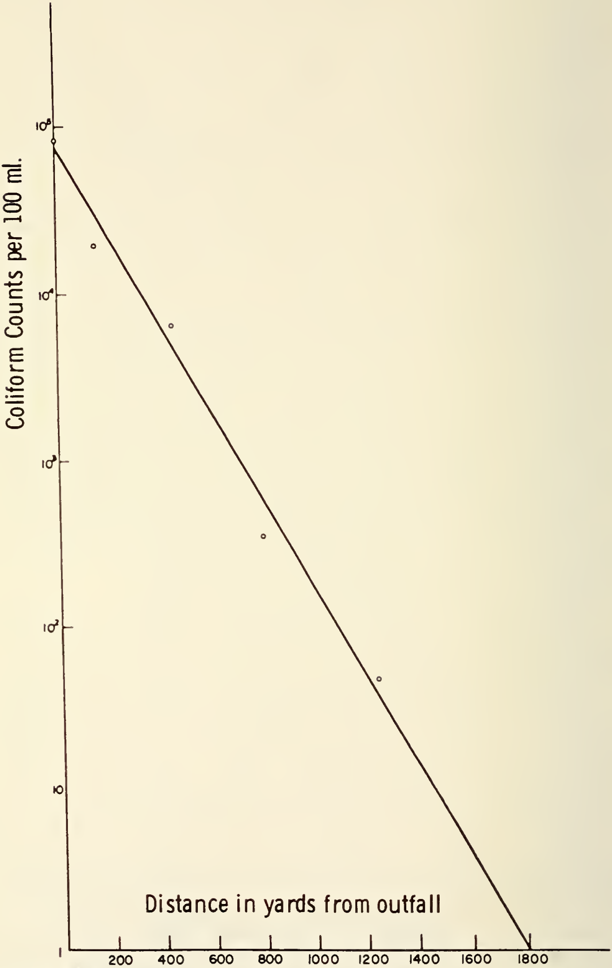

Fig. 4. Median coliform counts plotted against mean distance from the outfall (log-log transformation).

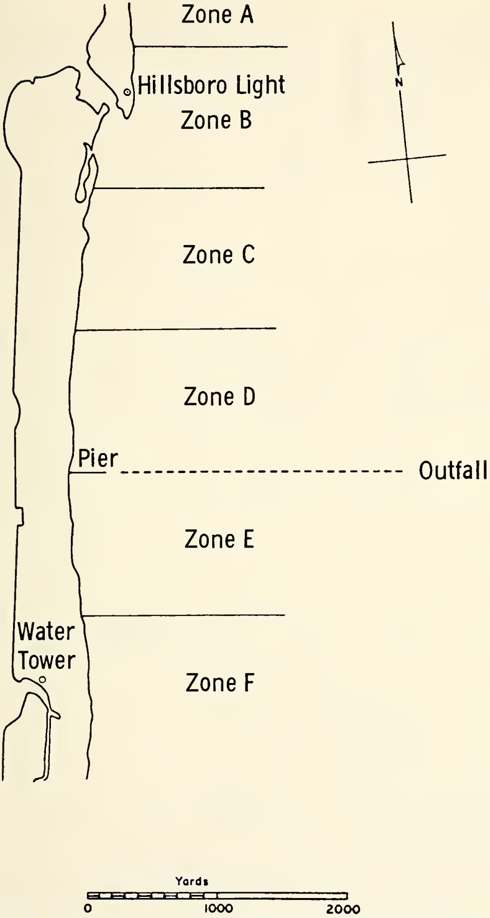

Fig. 5. Location of zones established for off-shore sampling (use with Table 3).

Bacteriologic Analysis of Beach Areas and Intracoastal Water. Samples were collected along transects perpendicular to the beach

TABLE 3

Coliform counts per 100 ml in samples on Transects from Beach to 1800 yards seaward. (Use with Fig. 5)

Tide	Zone	Distance in Yards From Beach									
	(Fig. 3)	100	300	400	600	800	1000	1200	1400	1600	1800
R 5 hrs	A	9			7			9			1
R 4 hrs	B			40			280			126	
F 5 hrs	B		16,000	9000		8000				3300	
F 1 hr	C	173	109		32					18	
		30	246		24					51	
F 1 hr	C		100							8	
F 5 hrs	C					1	6			33	
			64			23					
R 5 hrs	C	200	12			50					
R 5 hrs	D		100				1		0		
		1100	21	88			9			2	
F 3 hrs	D	1700									
R 4 hrs	E			1670		1400		584	665		16
				284*							
F 5 hrs	E			303*			252*			248*	93*
				321*							
F 5 hrs	E	15			11				10		
R 4 hrs	F	1600				700				452	

*Used FG Medium (Difco); counts represent fecal coli.

R, rising.
F, falling.

TABLE 4
Coliform counts per 100 ml from samples in the Intracoastal Canal and Pompano Beach (Hillsboro Inlet Areas)

Location	Canal	Beach*
Maximum	150,000	6000
Mean	12,900	1931
Median	2,300	500
Minimum	200	0
Number of Samples	20	26
% above $10^3/10^2$ ml	70	40

*Three samples showing TNTC at 1:1000 dilution not used in these data.

from 100 yards-1800 yards off-shore. For convenience, the areas of sampling are represented as zones shown in Fig. 5 which should be used for evaluation of the data in Table 3. In general, the coliform counts along these transects decreased with an increase of distance from the shore.

A summary of coliform counts from swimming areas along the beach between the Municipal Pier and the Hillsboro Inlet, and in Intracoastal waters are shown in Table 4. The counts in these areas show relatively heavy pollution.

A review of all the data leads to the conclusion that coliform counts decrease with the distance from the outfall, but, at a variable point approaching the shore, counts increase to a relatively high level. Although it is probable that the sewage outfall contributes small numbers of coliforms to the beach area, most of the indicated pollution on the beach probably comes from the Intracoastal Canal.

It is possible that levels of pollution in waters near the beach would be significantly higher than those predicted from extrapolation of the data. Brooks (1960) in his discussion of coefficient of diffusion curves, states that coliform counts may be increased to three-fold near the shore due to upwelling of bottom water and decreased flushing in shallow water. The location of a reef 600 yards off shore and west of the Pompano Beach outfall would probably accentuate this process of entrapment and concentration.

DISCUSSION

Coliform bacteria have a relatively short survival time in seawater as compared to fresh water. Reports in the literature show little agreement in the death rate of coliforms in seawater. Depending upon the experimental conditions and the strains of bacteria used, reported decimal reduction times vary from 3 hours-23 days (Carlucci and Pramer, 1960; Orlob, 1956). Studies in our laboratories (unpublished) of the survival times of coliforms in sewage-seawater mixtures show a decimal-reduction time of approximately 10 hours. In both aged seawater and sewage-seawater mixtures, *Enterobacter aerogenes* survives longer than *Escherichia coli.*

Coliform bacteria are not indigenous to marine waters and usually can be found only in those marine areas adjacent to sewage outfalls, estuaries, or marinas. Although the presence of coliforms in marine waters is good evidence of pollution by sewage, the absence of these bacteria can not be construed as evidence of safe water. The prolonged survival of viruses in seawater (Liu, et al., 1966) and their low infective dose (Plotkin and Katz, 1966) suggest that these agents must serve as the ultimate indicators of pollution with respect to health and sanitation.

Although every effort was made to maintain a separation of samples between inlet waters and sewage outfall waters by clearly discernible color differences, it seems probable that there is some mixing of these waters during tidal cycles which might have contributed some error to the outfall data.

Visual observation and the distribution of coliform counts indicate that there is a major dilution and dispersion of the sewage in the turbulence of cross-currents at the outfall. The stream of sewage frequently breaks up into pockets which become stabilized in prevailing current. Additional dilution appears to be slow except when additional eddies are formed. The current data given in this report have been confirmed and expanded by the more recent work of Lee (1969). He shows that the western edge of the Florida Current ranges from near shore to more than three miles sea-ward. He also describes large eddies which spin off from the western edge of the Florida Current and move counterclockwise toward the shore, south along the shore and ultimately back to the prevailing northerly stream.

Where these eddies contact the sewage plumes, additional dispersion and diversion of the sewage would occur. When these eddies do not divert the sewage plumes, they move for miles in the prevailing northerly current. On one occasion, counts ranging from 150-650 coliforms per 100 ml were found in a series of five samples collected eight miles north of the sewage outfall.

These observations and experimental data strongly indicate that low concentrations of sewage do reach surfing and swimming areas within two miles of the marine outfall at Pompano Beach. Conclusive evidence relative to the public health significance of these findings must await the development of better methods for utilizing viruses or other bacterial species as indicators of pollution.

The extension of existing and planned sewage outfall lines to terminate at the maximal western edge of the Florida Current would probably insure safe waters for recreational use. However, the continued use of marina outfalls for short-term economic disposal of sewage does not eliminate the loss of fresh water and potential fertilizer which will become increasingly needed resources if population densities are not stabilized at a rational ecological level.

SUMMARY

Studies are described which attempt to predict the extent of pollution from a marine sewage outfall in a location where the affected areas are subject to possible pollution from a second source. The data obtained from coliform counts combined with measurements of the Florida Current strongly indicate that existing and planned marine outfalls on the southeast coast of Florida do and will contribute low levels of pollution to off-shore and beach waters. The significance of these findings is discussed.

ACKNOWLEDGMENTS

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